

Using Drell-Yan to Probe the Underlying Event in Run 2 at CDF

Deepak Kar¹, Rick Field²

University of Florida, Gainesville, FL

On Behalf of the CDF Collaboration

Abstract

We study the event topology in Drell-Yan lepton-pair production in proton-antiproton collisions at 1.96 TeV in Run 2 at CDF. We use the direction of the lepton-pair on an event by event basis to define three regions of $\eta - \phi$ space; toward, away and transverse. The transverse and toward regions are very sensitive to the underlying event. The data are corrected back to the particle level and are then compared with the PYTHIA tune AW. The properties of the underlying event are examined as a function of the lepton-pair transverse momentum. The data are also compared with a previous analysis on the behavior of the underlying event in high transverse momentum jet production. The goal is to improve our understanding and modeling of the high energy collider events.

¹dkar@phys.ufl.edu

²rfield@phys.ufl.edu

1 Introduction

The goal of this analysis is to present measurements sensitive to the underlying event that are corrected back to the particle level so that they can be used to tune the QCD Monte Carlo models without requiring CDF detector simulation and to compare with a similar analysis done with the Tevatron jet data.

1.1 Underlying Event in a Typical Collider Event

A typical 2-to-2 hard scattering event in a proton-antiproton collision at the hadron colliders as shown in the Fig. 1. The incoming fundamental particles are the quarks and gluons inside the hadrons and the strong force is the dominant interaction.

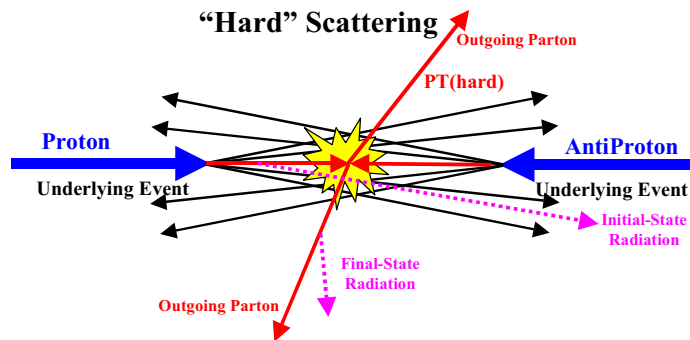


Figure 1: Components of a 2-2 Hard Scattering

Except the two hard scattered outgoing partons - the landscape is dominated by initial and final state radiation (caused by bremsstrahlung and gluon emission), resonance decays, multiple parton interaction (additional 2-to-2 scattering within the same event), hadronization, beam beam remnants (particles that come from the breakup of the proton and antiproton) and so on.

We define the ‘underlying event’ as everything except the two outgoing hard scattered

‘jets’ and consists of the ‘beam-beam remnants’ plus initial and final-state radiation[1]. However experimentally, it is impossible to separate out the two components. The ‘hard scattering’ component consists of the outgoing two ‘jets’ plus initial and final-state radiation. The ‘beam-beam remnants’ are what is left over after a parton is knocked out of each of the initial two beam hadrons as in Fig. 3. It is the reason hadron-hadron collisions are more ‘messy’ than electron-positron annihilations and no one really knows how it should be modeled. Also, it is possible that multiple parton scattering, as in Fig. 2 contributes to the ‘underlying event’. In addition to the hard 2-to-2 parton-parton scattering and the ‘beam-beam remnants’, sometimes there is a second ‘semi-hard’ 2-to-2 parton-parton scattering that contributes particles to the “underlying event” as in Fig. 2.

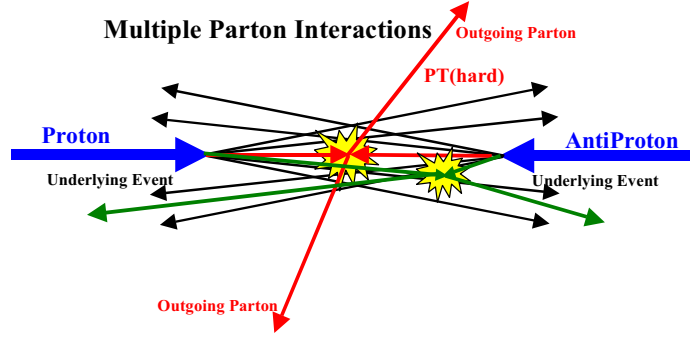


Figure 2: Multiple Parton Interactions

1.2 Transverse, Toward and Away Regions

We would now define and look at the different regions at a collider event. The angle $\Delta\phi = \phi - \phi_{leadingjet}$ is the relative azimuthal angle between charged particles and the direction of hard scattered leading jet. Later we would be looking at lepton pair production from Z boson, $\Delta\phi$ would then be determined relative to the direction of Z boson. Now we

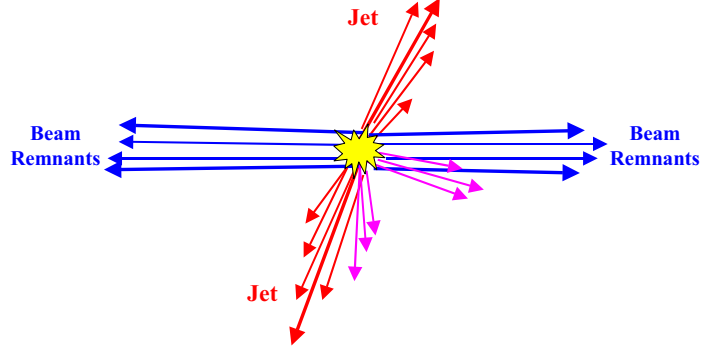


Figure 3: Beam Beam Remnants

can split the central region, defined between $|\eta| < 1$ as in Fig. 4.

- $|\Delta\phi| < 60^\circ$ as toward region.
- $60^\circ < -\Delta\phi < 120^\circ$ and $60^\circ < \Delta\phi < 120^\circ$ as transverse regions. And,
- $|\Delta\phi| > 120^\circ$ as away region.

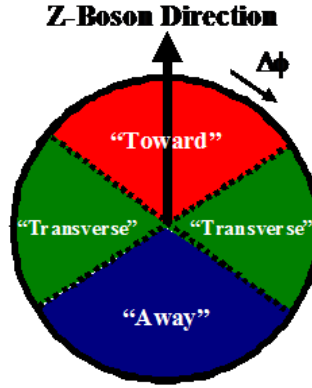


Figure 4: Different Regions in $\eta - \phi$ space

For hard scattered jets, where the relative azimuthal angle is with respect to the leading jet direction, the transverse regions are the most sensitive to underlying events, since they

are perpendicular to the plane of 2-to-2 hard scattering. For them we have outgoing jets in transverse regions, almost impossible to separate them out from the background.

1.3 The Drell Yan Process

Quarks and antiquarks from the incoming hadron beams annihilate to produce a virtual photon or Z^0 , which decays to a lepton pair (e^+e^- or $\mu^+\mu^-$).

The Drell-Yan Process

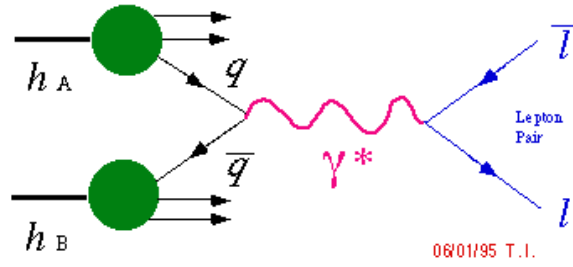


Figure 5: Drell Yan Process

Let us compare the underlying events in a hard scattering as in Fig. 1 with underlying events in Drell Yan process.

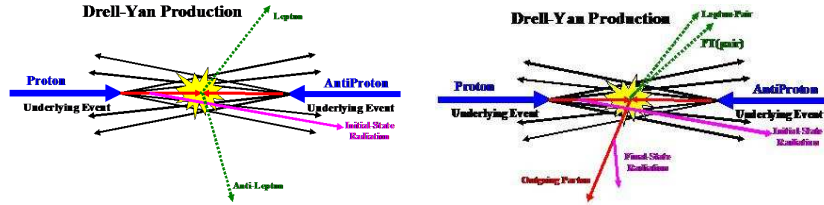


Figure 6: Underlying event in Drell-Yan. Left: Low P_T , Right: High P_T

By looking at the diagram we can see that essentially everything other than the final lepton-antilepton pair is the underlying event for the low P_T case. For Drell-Yan it is easy

to identify and remove leptons (since they are the colorless components) from the transverse and toward regions to study the underlying event.

Single Z Bosons are produced with large P_T via the ordinary QCD sub processes, generating additional gluons via bremsstrahlung resulting in multi-parton final states fragmenting into hadrons and forming away-side jets. The transverse region is perpendicular to the hard scattering and once we remove the lepton pair from the toward region we are left with only underlying event in these two regions.

So we can see not only Drell Yan events are a clean probe of the underlying event but also we can study the underlying event as a function of lepton pair transverse momentum or invariant mass. Comparing them with high P_T jet production would help us to learn more about underlying event in general. And at the same time we would be able to look at Z boson P_T distribution, which would be an extra way to constrain our underlying event model.

2 Analysis Strategy

2.1 Data Selection

We analyze the high P_T electron and muon Data and corresponding PYTHIA[2] tune AW[3] (tuned to fit the underlying event and the Z-boson P_T distribution measured in Run 1[4]) samples, as shown in Table 1. We analyzed data corresponding to the luminosity of approximately 2.3 fb^{-1} . We select only events having one and only one vertex within $|Z_{vtx}| < 60$ cm. It measures the distance of the $p\bar{p}$ collision event vertex from the center of the detector in z direction. To ensure that a track for each charged particle is well measured by the

tracking system, we need this requirement.

Table 1: Data and Monte Carlo samples used in this analysis

Lepton	Monte Carlo	DATA
Electron	Drell- Yan $Z/\gamma^* \rightarrow ee$ sample	high- P_T Central electrons
Muon	Drell- Yan $Z/\gamma^* \rightarrow \mu\mu$ sample	high- P_T CMUP and CMX muons

2.2 Lepton Selection and Pair Formation

The electron and muon selections are based on the standard CDF high P_T electron and muon[5] selection criteria. An electron is a cluster of electromagnetic energy with $E_T > 18$ GeV and $|\eta| < 1.1$ matched to a track with $P_T > 10$ GeV/c with further requirements on position matching and shower shape in the CES. We look at central electrons, with tight and loose cuts described in [5]. We also remove conversions from photon by finding the partner track during the electron selection[6]. We look at the CMUP and CMX muons. A muon is a track with $P_T > 18$ GeV/c and $|\eta| < 1$ and a track segment in the muon chamber that matches the extrapolated position of the track. The only extra cut we make is on χ^2/DoF (the track χ^2 cut is based on the COT of the parent track and it is assumed that the number of degrees of the freedom is 5 less than the number of COT hits) - which helps to eliminate cosmic muons. Apart from that, to get rid of cosmic muons, we also use a Time of Flight (TOF) cosmic filter, as the time difference between the muons recorded in the upper and lower half of the detector is expected to be very small for muons not coming from cosmic rays.

The lepton pairs are formed by oppositely charged leptons, with the requirement that z_0 of the two leptons must pass $|z_0^1 - z_0^2| < 4$ cm, to ensure that both leptons came from

the same primary collision. For electrons, we form pairs with at least one tight electron, as defined earlier. For Muons, there is no such distinction.

We focus on the region of the lepton pair invariant mass between 70 and 110 GeV/ c^2 , which we refer to as the Z -region hereafter. Approximately 50,000 electron and muon pairs combined passed our selection criteria and are used in the analysis. We use the same selection criteria for data and detector level Monte Carlo.

The $Z \rightarrow e^+e^-$ and $Z \rightarrow \mu^+\mu^-$ data sample contains backgrounds mainly from QCD jets and W +jets. Studies[5] have shown that these backgrounds are negligible at the region of Z .

2.3 Charged Particle Selection

Only charged particles in the region of $0.5 \text{ GeV}/c < P_T < 150 \text{ GeV}/c$ and $|\eta| < 1$, where efficiency is high are considered. The upper limit of P_{Tmax} cut is chosen as 150 GeV/ c to prevent miss-measured tracks with very high P_T from contributing to the observables. The tracks are defined to be loose and tight according to track $|d_0|$ (transverse impact parameter defined as the minimum distance between the track and the primary vertex in the plane transverse to the beam direction - small value means the particle originates from near the interaction region) and track $|\Delta z|$ (measured longitudinal distance between the measured track and the primary vertex). We also make sure none of the charged particles are electrons coming from pair production from photon[6].

2.4 Observables

Some of the observables that are studied in this analysis are described in Table 2. Since we would be studying regions in $\eta - \phi$ space with different areas, as defined in Section 1.2 we will construct densities by dividing by the area. The mean charged particle $\langle P_T \rangle$ is constructed on an event by event basis and then averaged over the events. For the average P_T and P_{Tmax} we require that there is at least one charged particle present. The P_{Tsum} (hence the P_{Tsum} density) is taken to be zero if there are no charged particles present.

Table 2: Observables

Observable	Particle Level	Detector Level
Lepton P_T	P_T of the lepton pair	P_T of the lepton pair, formed by at least one tight lepton.
Lepton P_T Squared	P_T squared of the lepton pair	P_T squared of the lepton pair, formed by at least one tight lepton.
Charged Density	Number of charged particles per unit $\eta - \phi$	Number of ‘good’ charged tracks per unit $\eta - \phi$
$\langle P_T \rangle$	Average P_T of charged particles	Average P_T of ‘good’ charged tracks
P_T Sum Density	Scalar P_T Sum of charged particles per unit $\eta - \phi$	Scalar P_T Sum of ‘good’ charged tracks per unit $\eta - \phi$
P_{TMax}	Maximum P_T of charged particle	Maximum P_T of ‘good’ charged tracks

2.5 Correcting Back to Particle Level

We use the ratio of the generator level Monte Carlo result and the detector level Monte Carlo result as our correction factor for correcting the data back to the particle level. Our generator level results are formed by adding both electron and muon results together, since

in theory, they are expected to and indeed are found to be consistent. We do not apply any kinematic cuts on leptons in particle level.

2.6 Systematic Uncertainties

We correct the data back to particle level in three different ways for electron, and in two different ways for muon. We take the differences at particle level between (1) loose-tight and tight-tight electron selection and (2) loose and tight track cuts for charged particles as systematic uncertainties for electron data. For muon data, the differences between loose and tight track cuts are taken as systematic uncertainties. We add the different systematic errors in quadrature, and add the statistical error with that in quadrature with that to draw one combined error bar. We observed that the differences between different cuts do not produce a significant systematic uncertainty and the dominant contribution to our total uncertainties are statistical. When comparing with the dijet ‘underlying event’ data later, we would see that they have much smaller statistical (hence overall) uncertainties, as dijet events have more statistics.

3 Results

3.1 Z Region Results

As mentioned earlier, we present results on the underlying event observables in the events with the lepton pair invariant mass in the z boson region, *i.e.* 70-110 GeV/ c^2 . The presented results refer to all the charged particles with $P_T > 0.5$ GeV/ c and $|\eta| < 1$. We have combined our electron and muon results. The underlying event observables defined in Section 2.4 are shown as a function of the lepton pair p_T in Figs. 7-26. We present results for lepton

pairs with $P_T < 100 \text{ GeV}/c$, above which we do not have enough statistics. The underlying event observables are found to be reasonably flat with the increasing lepton pair P_T in the transverse and toward regions, but goes up in the away region to balance lepton pairs. We overlay transverse and toward regions for each observable in the same plot for comparison purpose, and then overlay the away region with them to see this effect. In some of the plots, we also show Herwig[8] predictions, which without the multiple parton interactions added through Jimmy[9], gives a much smaller underlying event.

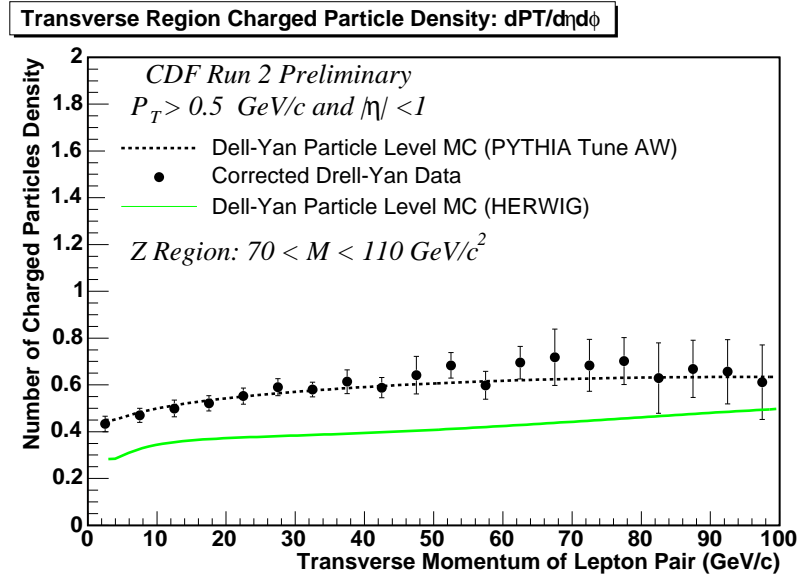


Figure 7: Transverse Region Charged Multiplicity Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

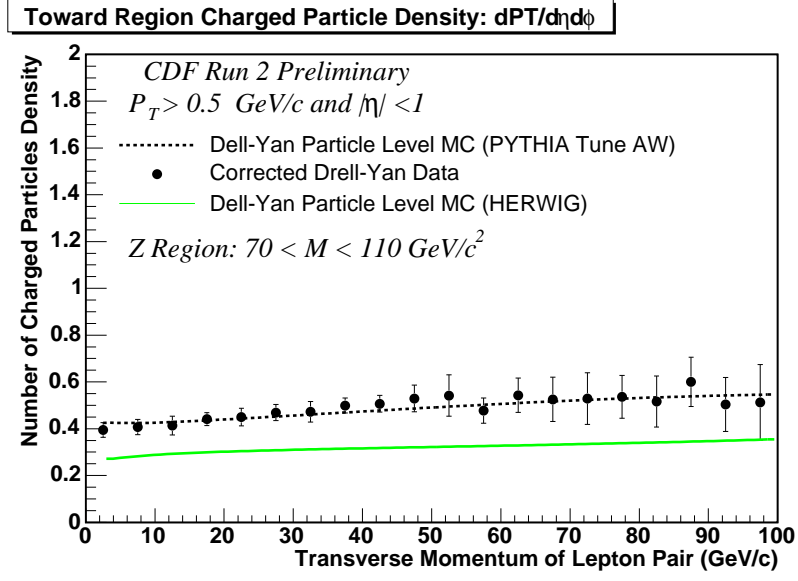


Figure 8: Toward Region Charged Multiplicity Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

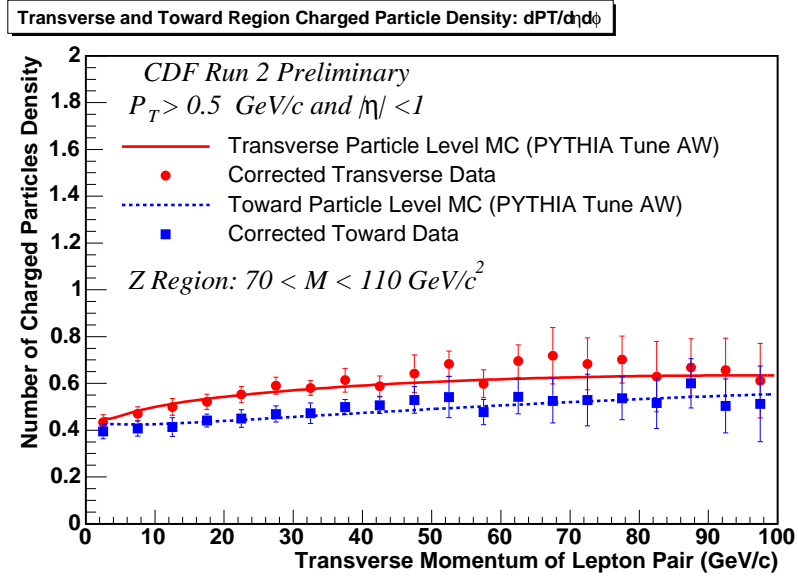


Figure 9: Transverse and Toward Region Charged Multiplicity Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

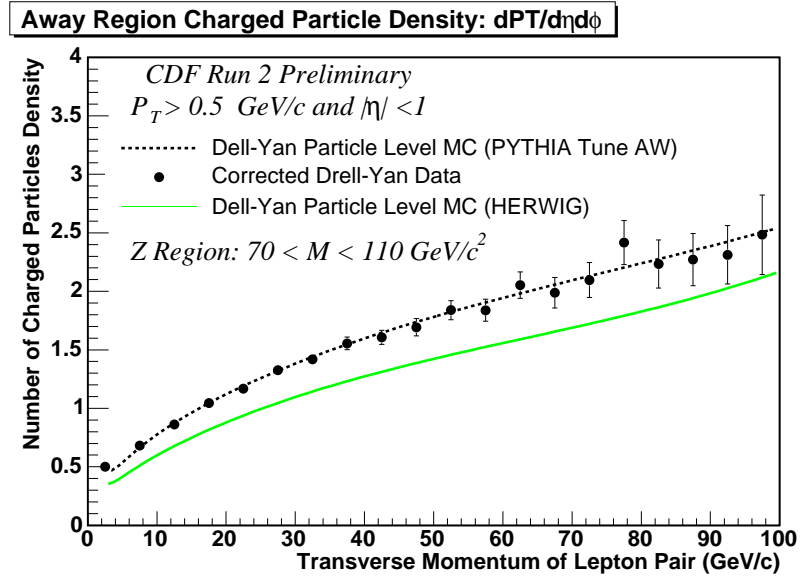


Figure 10: Away Region Charged Multiplicity Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

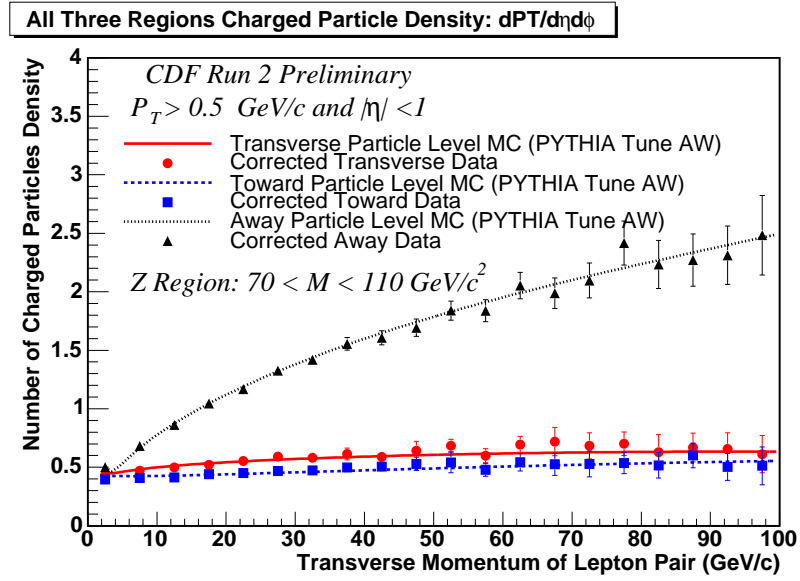


Figure 11: All Three Regions Charged Multiplicity Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

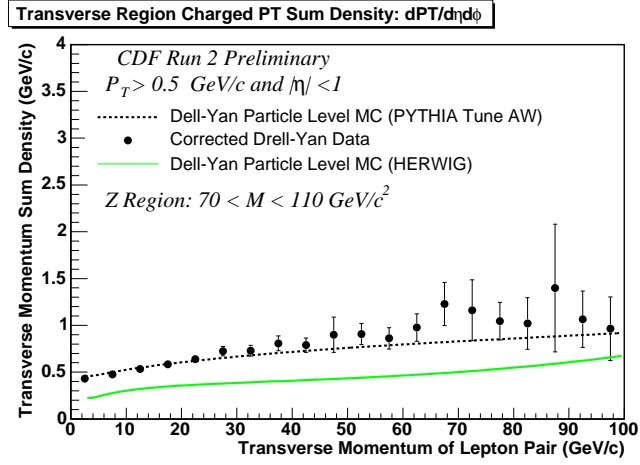


Figure 12: Transverse Region Charged P_T Sum Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

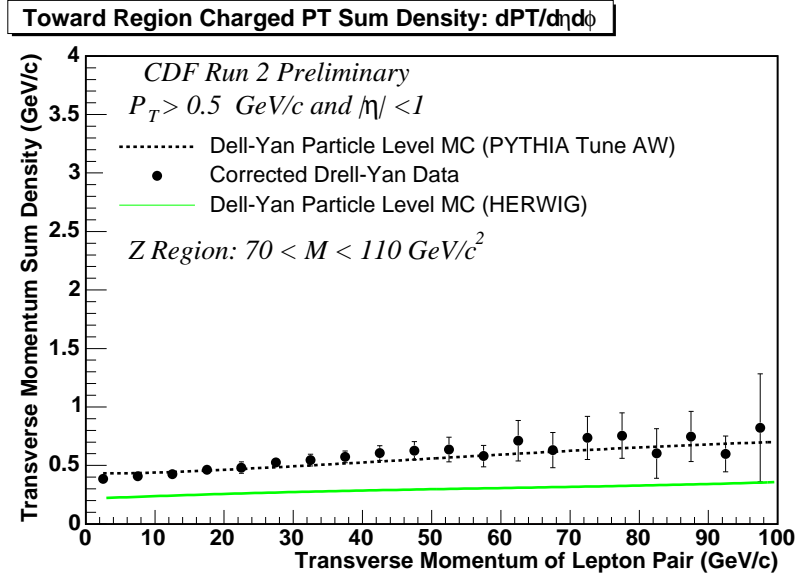


Figure 13: Toward Region Charged P_T Sum Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

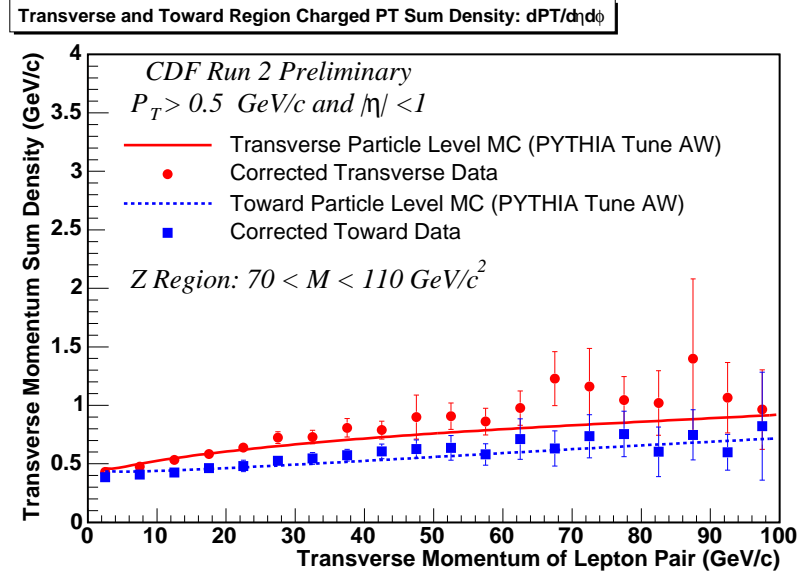


Figure 14: Transverse and Toward Region Charged P_T Sum Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

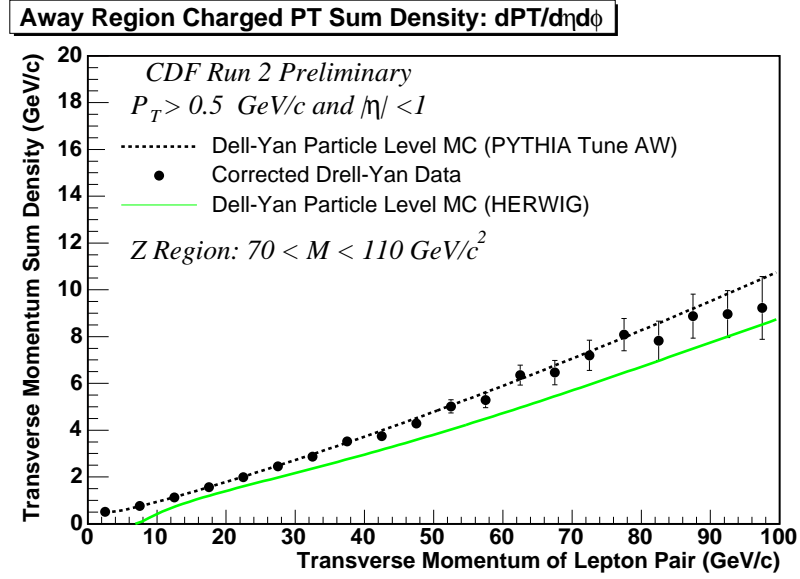


Figure 15: Away Region Charged P_T Sum Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

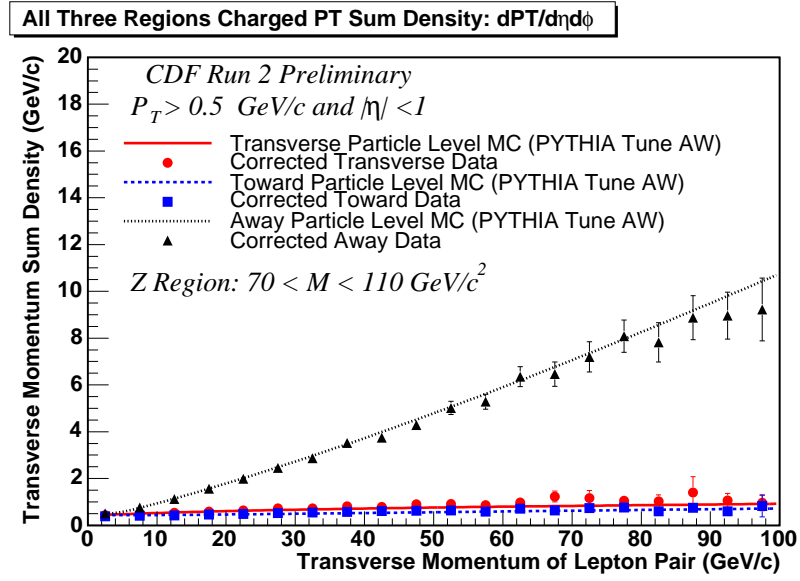


Figure 16: All Three Regions Charged P_T Sum Density, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

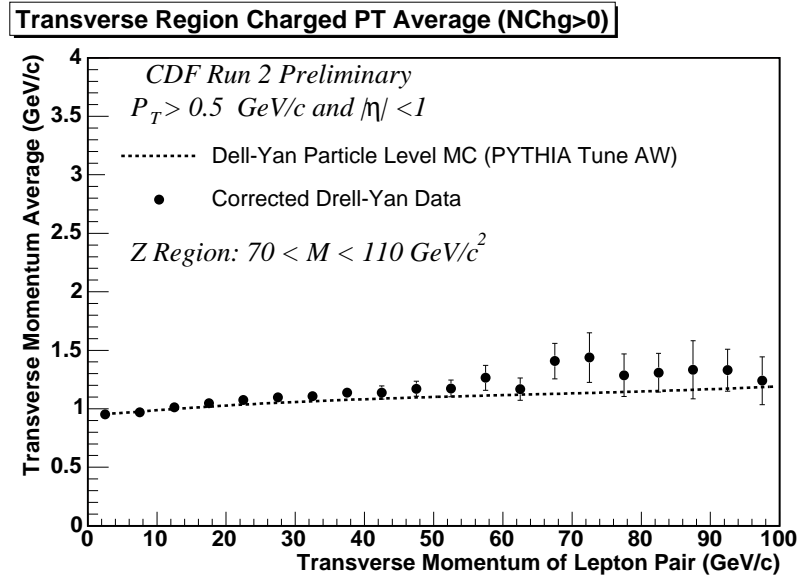


Figure 17: Transverse Region Charged P_T Average, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

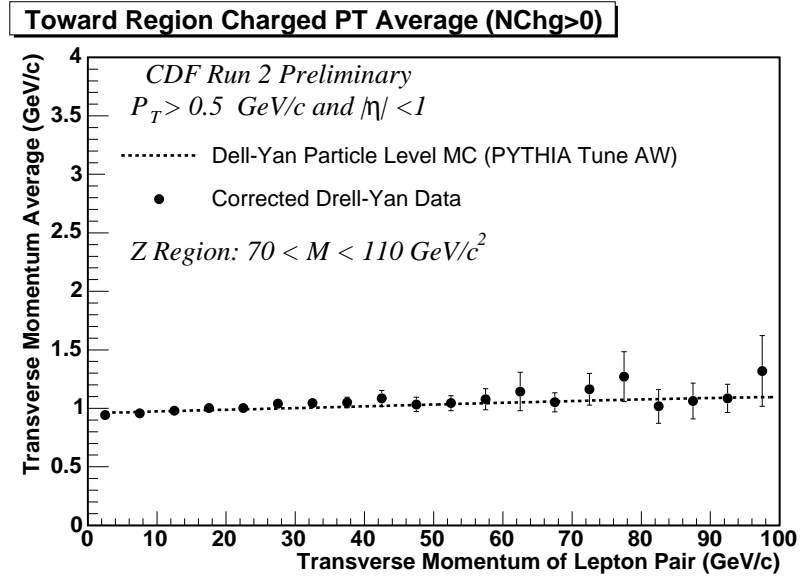


Figure 18: Toward Region Charged P_T Average, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

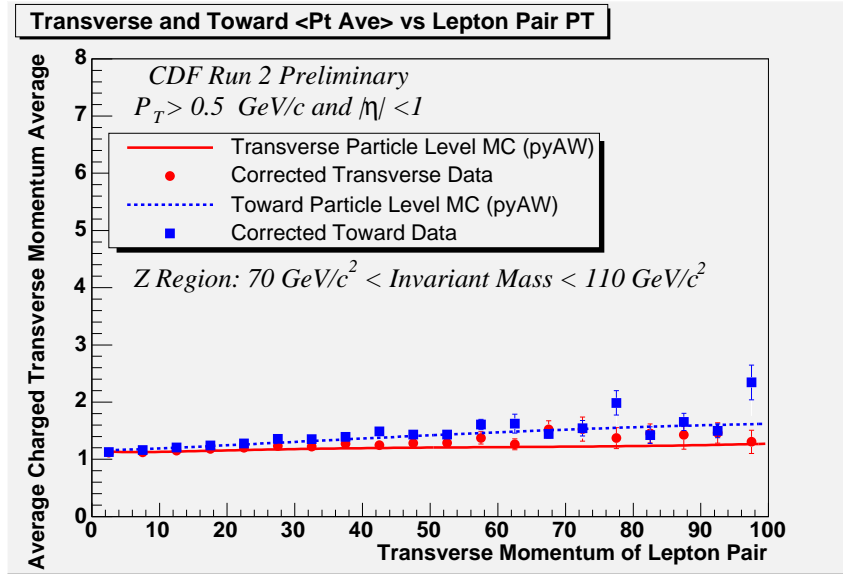


Figure 19: Transverse and Toward Region Charged P_T Average, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

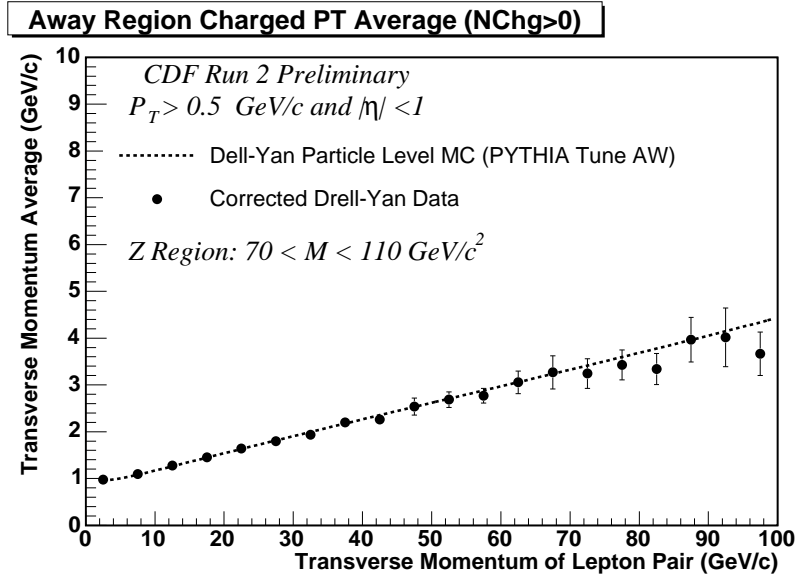


Figure 20: Away Region Charged P_T Average, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

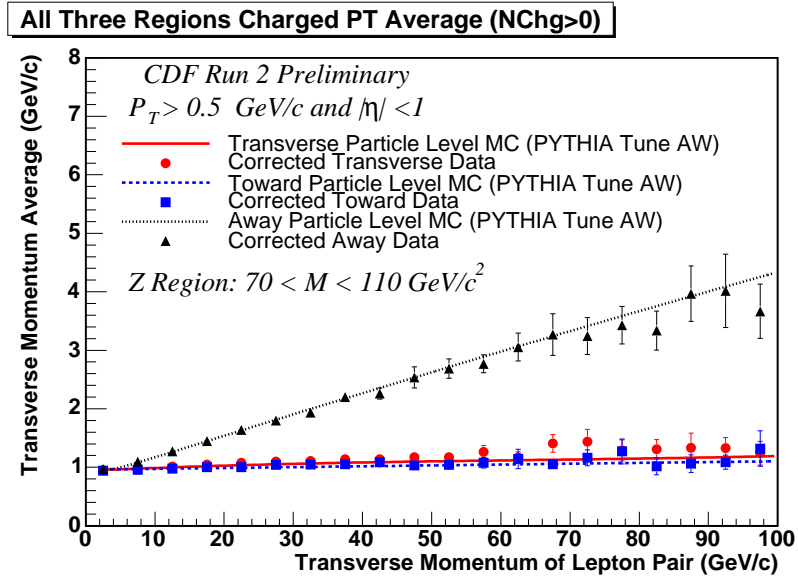


Figure 21: All Three Regions Charged P_T Average, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

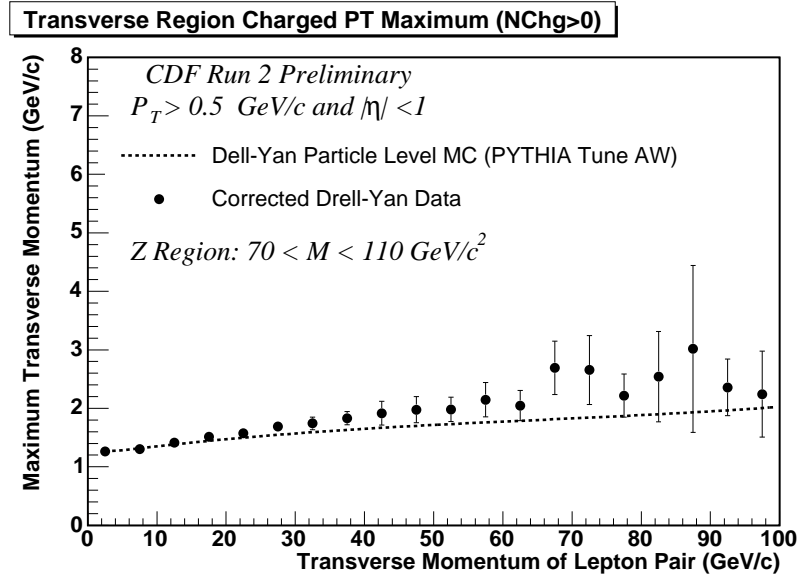


Figure 22: Transverse Region Charged P_T Maximum, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

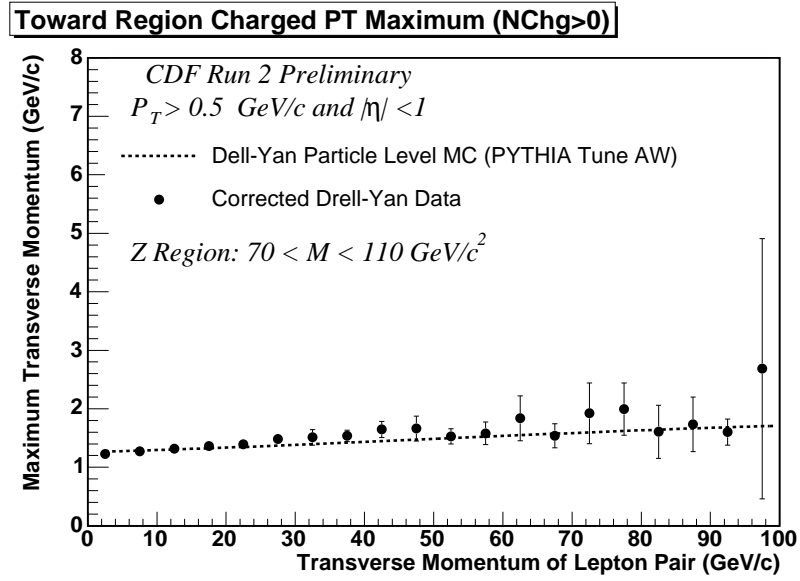


Figure 23: Toward Region Charged P_T Maximum, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

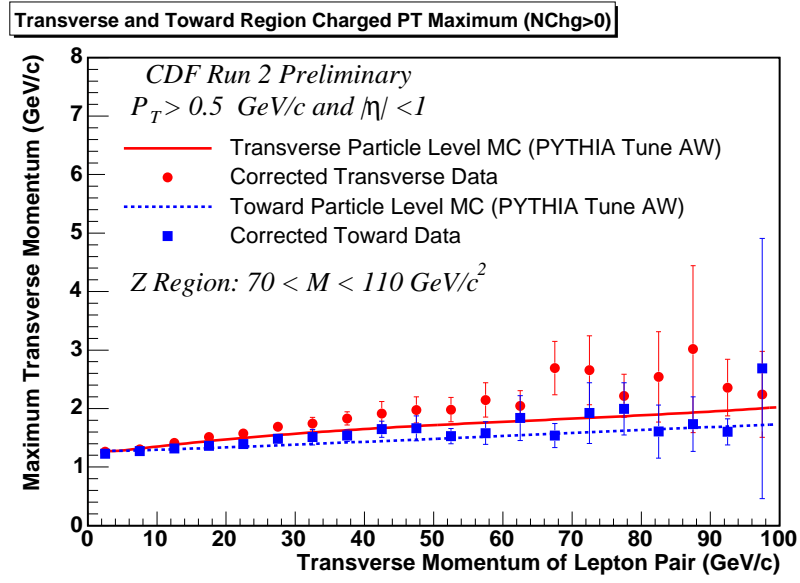


Figure 24: Transverse and Toward Region Charged P_T Maximum, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

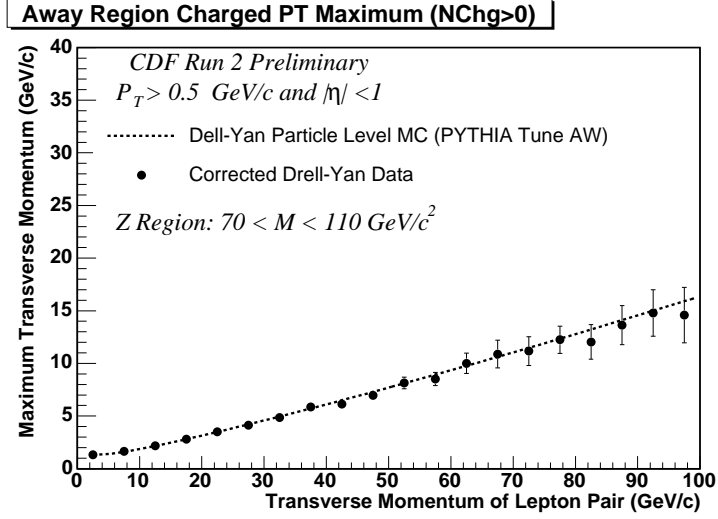


Figure 25: Away Region Charged P_T Maximum, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

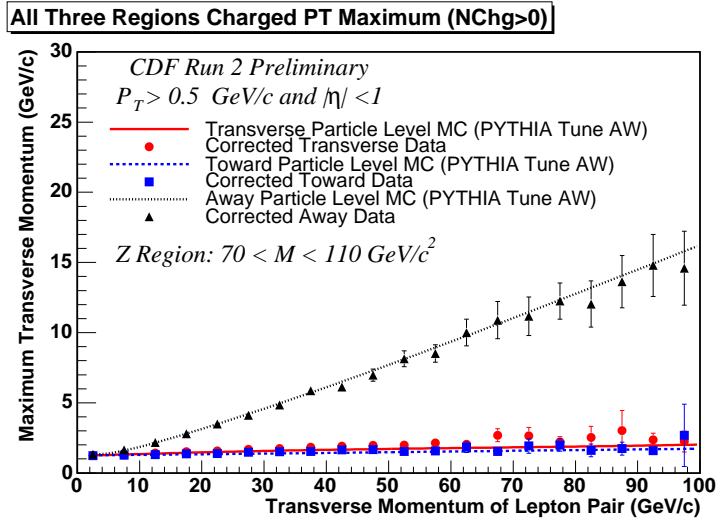


Figure 26: All Three Regions Charged P_T Maximum, Data Corrected, Electron and Muon Data Combined ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

3.2 Comparisons with Leading Jet Underlying Event

Here we compare our results with leading jet underlying events results from [10]. Mostly we observe a very good agreement, as expected. We have to note that dijet and Drell-Yan events have distinct topologies. At very low P_T , Z-boson still has the large invariant mass, whereas we only get minbias events for dijet in that region - which explains the apparent differences between dijet and Drell-Yan ‘underlying events’ in low P_T region. The away-side jet in dijet events are not constrained to be in the away region, and that explains the difference with Drell-Yan results.

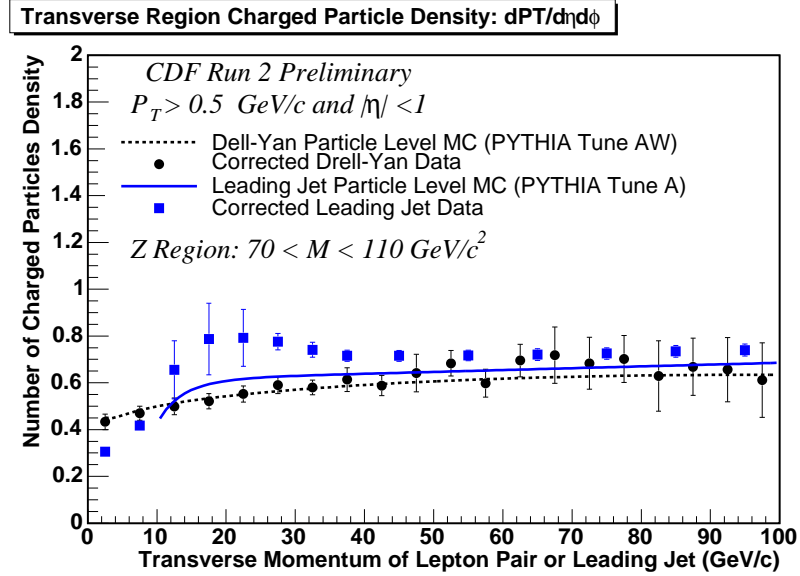


Figure 27: Transverse Region Charged Multiplicity Density, Data Corrected, Electron and Muon results combined, compared with Leading Jet result ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

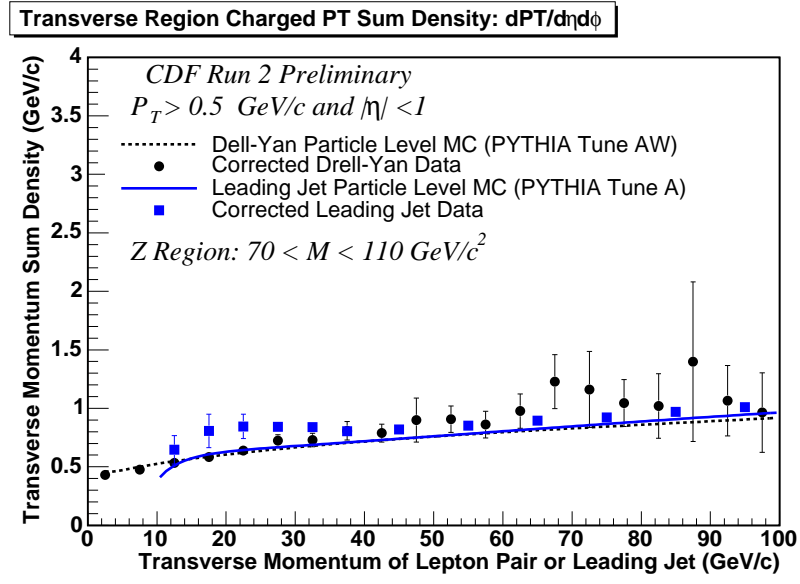


Figure 28: Transverse Region Charged P_T Sum Density, Data Corrected, Electron and Muon results combined, compared with Leading Jet result ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

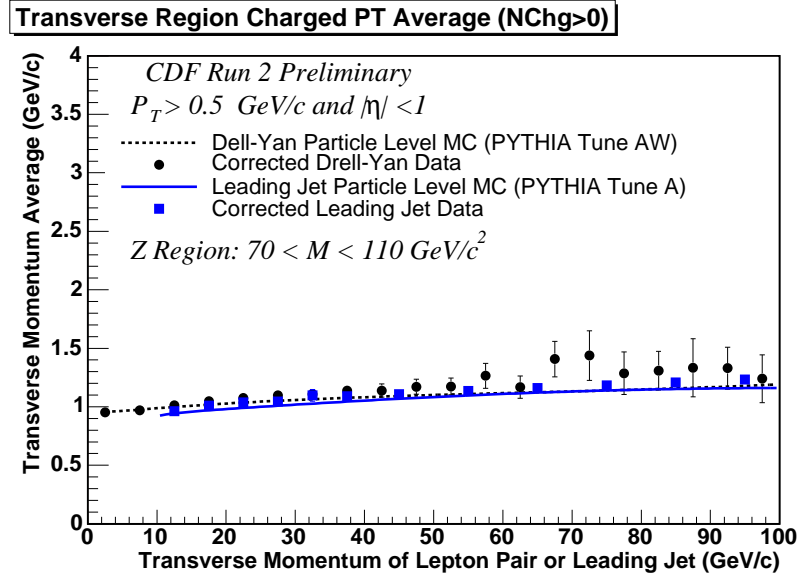


Figure 29: Transverse Region Charged P_T Average, Data Corrected, Electron and Muon results combined, compared with Leading Jet result ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

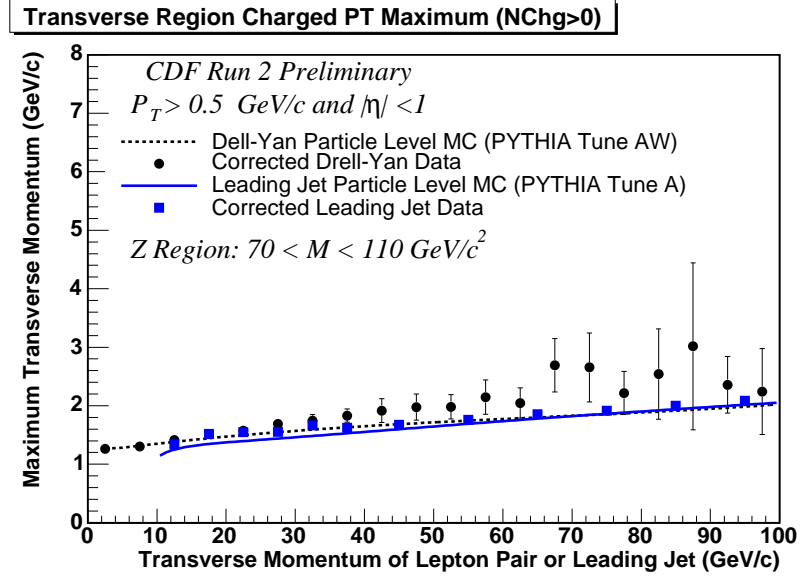


Figure 30: Transverse Region Charged P_T Maximum, Data Corrected, Electron and Muon results combined, compared with Leading Jet result

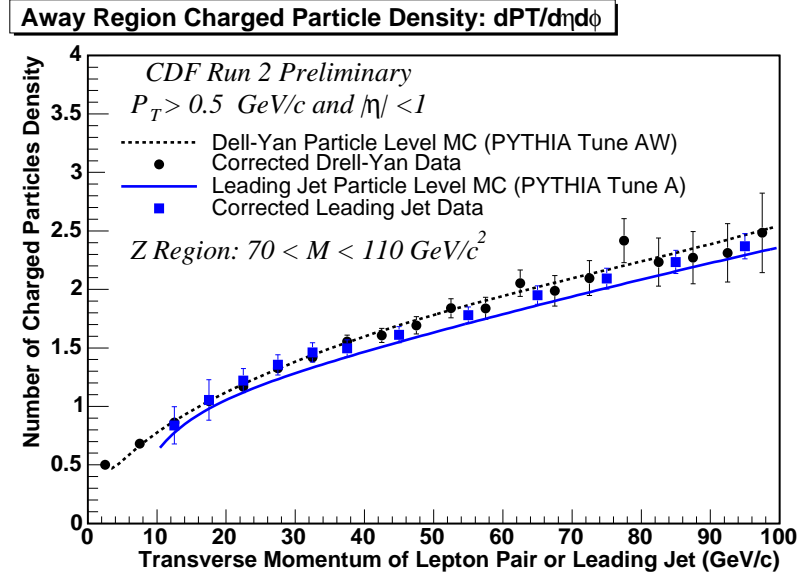


Figure 31: Away Region Charged Multiplicity Density, Data Corrected, Electron and Muon results combined, compared with Leading Jet result ($P_T > 0.5 \text{ GeV}/c$ and $|\eta| < 1$)

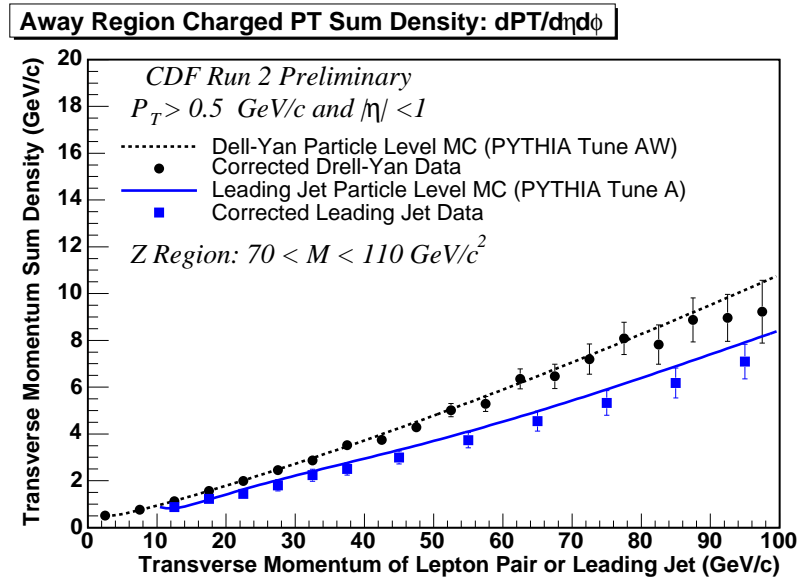


Figure 32: Away Region Charged P_T Sum Density, Data Corrected, Electron and Muon results combined, compared with Leading Jet result ($P_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$)

3.3 Summary

We studied the underlying event variables associated with Drell Yan lepton pair production and mostly observed excellent agreements with PYTHIA tune AW Monte Carlo predictions. We also compared them with leading jet underlying event results and observed reasonably close agreement - which may indicate the universality of underlying event modeling. We observe a slight excess at transverse region compared to toward region, which is caused by transverse regions receiving contributions from away side jet.

References

- [1] Rick Field
Studying the Underlying Event at CDF
Proceedings 33rd International Conference on High Energy Physics (ICHEP 06),
Moscow, Russia.
- [2] T. Sjostrand et al.
High-Energy-Physics Event Generation with PYTHIA 6.1
Comput. Phys. Commun. **135**, 238 (2001).
- [3] Rick Field
CDF Run 2 Monte-Carlo Tunes
CDF/PHYS/JET/PUBLIC/8547.
- [4] F. Abe *et al.*, The CDF Collaboration
Measurement of the Z PT Distribution in proton-Antiproton Collisions at 1.8 TeV,
The CDF Collaboration
Phys. Rev. Lett. **67**, 2937-2941 (1991).
- [5] A. Abulencia *et al.*, The CDF Collaboration
*Measurements of Inclusive W and Z Cross Sections in p anti-p Collisions at $s^{**}(1/2)$*
= 1.96 TeV
J. Phys. G: Nucl. Part. Phys. 2457-2544 (2007).
- [6] D. Acosta *et al.*, CDF Collaboration
Measurement of the cross section for tt production in pp collisions using the kinematics

of lepton jets events

Physical Review D **72**, 052003 (2005).

[7] Phys. Rev. Lett. 100, 102001 (2008)

[8] G. Corcella et al.

HERWIG 6: An Event Generator for Hadron Emission Reactions with Interfering Gluons (including supersymmetric processes)

JHEP **01**, 10 (2001).

[9] J.M.Butterworth, J.R.Forshaw and M.H.Seymour

Multiparton interactions in photoproduction at HERA

Z.Phys. C**72**, 637 (1996).

[10] Alberto Cruz and Rick Field

Using Correlations in the Transverse Region to Study the Underlying Event in Run 2 at the Tevatron

CDF Public Note - CDF/PUB/JET/PUBLIC/6821

[11] Richard D.Field, Research Webpage

http://www.phys.ufl.edu/~rfield/RDF_res.html

[12] Drell Yan figures

<http://www.rarf.riken.go.jp/rarf/rhic/phys/DY/DY.html>